Connectivity among three restored *Crassostrea virginica* bars in the Severn River Estuary; Implications for oyster recovery efforts

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Introduction/Rationale

In an effort to improve water quality and enhance the *Crassostrea virginica* fishery, many oyster restoration bars have been placed in Chesapeake Bay and its tributaries. While recent spat-on-shell plantings have shown promise for juvenile survival, the cost of replacing laboratory-reared spat on restored beds may prohibit large-scale restoration initiatives. Nevertheless, bars are often placed in sub-estuaries with poorly described physical conditions and circulation dynamics. Therefore the potential for the restored bars to either re-seed themselves or serve as larval sources for other beds remains unclear.

Objectives

In this project we sought to describe the physical and biological (planktonic) habitat at 3 oyster restoration sites in Chesapeake Bay tributaries (College Creek (CC), Weems Creek (WC), and Lake Ogleton (LO); Annapolis, Maryland USA, Figure 1), and begin to evaluate ecological connectivity among those sites. Specifically, this work had the following 5 goals:

1) To determine whether temperature and salinity at the 3 restoration sites favor both the survival of the adults and spat placed there, and oyster spawning.
2) To use real-time current velocities and wind data to predict larval trajectories, in the event that physical conditions are favorable for spawning.
3) Ground-truth the simulated trajectories with ARGOS-tracked Lagrangian drifters.
4) To determine whether or not the planktonic assemblages in the vicinity of the restored bars include oyster larvae, and quantify how the zooplankton assemblage changes seasonally.
5) To engender collaborations with research groups at other institutions.

Methods

Physical Habitat

To determine whether or not conditions at each of the 3 restored oyster bars were favorable for both spawning of adults and survival of spat and juvenile oysters, temperature and salinity were monitored at each of the sites throughout the potential oyster spawning season in 2007. At the College Creek site, temperature, salinity, and dissolved oxygen were measured daily at 0.5m, 1.0m, and 3.0m with a YSI-85 hand-held meter. Temperature and salinity at Weems Creek and Lake Ogleton were measured weekly at high slack water from May 21 to October 2, 2007 at 0.5m and ~0.5m above the bottom.

As part of a collaborative effort with D. Fredriksson (USNA Ocean Engineering Department) an Acoustic Wave and Current Meter (AWAC) was deployed in College Creek during July 2007, and in the Severn River from September-November 2007. These data will be used to validate a circulation model of the Severn River.

Transport and Connectivity

To assess connectivity among restoration sites and to simulate potential trajectories of larvae released from the bars, a total of six satellite-tracked Lagrangian

drifter deployments were conducted from the College Creek bar in May-June, 2007, and September-December 2007. Deployments did not occur during June-August as originally planned because a drifter was perceived as a security threat, recovered and destroyed during USNA's Commissioning Week, and a shipment of drifters expected in spring 2007, did not arrive until November, 2007.

Planktonic Assemblages

The planktonic community at the College Creek, Weems Creek and Lake Ogleton restoration sites was characterized via weekly surface plankton tows (Miller plankton net, 63μm mesh) at the bars from May 21 to October 2, 2007. Tows coincided with collections of the physical data described above. On two dates (June 15 and September 14), sampling at Lake Ogleton was precluded due to boat trouble and inclement weather. Replicate tows were conducted at each station, and all samples were collected between 0800 and 1600 at approximately the time of high slack water. Starting on June 6, a General Oceanics Model 2030 flowmeter was deployed with each tow to quantify sample water volume. Samples were returned to the lab, concentrated on a 63 μm sieve and preserved in 70% EtOH. Samples were spot-checked once every 2 weeks for presence of *C. virginica* larvae.

Spat settlement

C. virginica spat size, mortality, and spat settlement at each of the three sites was quantified in the fall of 2007. SCUBA divers from the USNA Dive Locker collected oysters from replicated randomly placed $0.25m^2$ quadrats at each site, following the methods of the Chesapeake Bay Foundation (Stephanie Reynolds, Personal Communication). Oysters were brought to the lab, described as alive or dead ("boxes"); checked for spat; and measured (length and width); and returned to their original site. Data collected at CC were compared to those of the Chesapeake Bay Foundation. Oyster size and mortality data had not been previously collected by any organization at the WC or LO, so could not be compared to assess growth.

Acoustic Characterization of the Weems Creek Bar

Because of the high costs and logistical challenges of mapping and monitoring restored oyster bars via SCUBA, in the spring of 2008 we sought to determine if oyster health, growth, or bar topography could be assessed via acoustic a small, portable acoustic camera. On April 7, 2008, a Blueview Pro Viewer E imaging sonar camera was used to take images of the Weems Creek Bar. The imaging sonar was attached to a fiberglass pole to allow the operator to rotate it 360 degrees. At the station, the instrument was lowered into the water and manually calibrated for the best picture. Both 360˚ point-scans and 4 transects parallel the bar were run, and the data were assessed examining the video visually.

Results/Discussion

Physical habitat

Even using conservative estimates of the required temperatures and salinities (18-20C/ salinity>12), in the summer of 2007, physical conditions were favorable for *C. virginica* to spawn at all three stations sampled (Figures 2-4). Salinities were generally highest at the Lake Ogleton station, implying that given sufficient broodstock, spawning may have occurred at this station as early as mid-July.

Transport and Connectivity

All of the drifters deployed from the CC site in 2007 remained within the College Creek/ Severn River system (Figure 5). This may have been due to a combination of relatively weak bay-ward winds in the study period at the time, and due to grounding and dragging of the drogues in the shallow reaches of the Severn River tributaries. Previous data from the spring of 2007 illustrated a high degree of retention in the Severn as well, and this will be tested further in the summer of 2008.

Planktonic Assemblages

Spot checks of the plankton samples collected in 2007 did not turn up any *C. virginica* larvae. However, identification of the planktonic assemblages within those samples is ongoing, and the data will be used to characterize the zooplankton community at the 3 stations.

Spat Settlement/growth

Although temperatures and salinities favored spawning at all three stations in the summer of 2007, no spat settled at any of the site. While most adult *C. virginica* were alive and appeared healthy at CC and WC (Figures 6, 7), no live oysters were collected at LO. This may have been due to illegal harvesting that occurred at LO in the spring of 2006. Comparison of oyster sizes measured at CC in this study with CC in previous years indicated steady growth of the oysters from the time they were planted in 2002 (Figure 7). The survival and growth of the adult oysters found at CC and WC study agreed well with our physical measurements which indicated temperatures and salinities favorable throughout the year for adult *C. virginica* survival.

Acoustic characterization

The data from the acoustic camera could be used to determine the lateral extent of the bar in two dimensions, as well as the bathymetric features within the bar (Figure 8), yet could not resolve the size or condition of individual shells. While other mapping options such as side scan sonar may be able to provide more complete coverage of the region in which *C. virginica* restoration bars are placed, the ease of use and portability of the acoustic camera could make it a viable tool for high-resolution mapping of bars in shallow waters. For growth and mortality studies, however, traditional sampling methods using SCUBA or sampling via hand tongs still prove necessary.

Summary

We reached 3 of the 5 objectives of this study. Namely we showed that temperatures and salinities at CC, WC and LO favored spawning of *C. virginica*, and survival of the adults and spat (Objective 1). Next we preliminary determined that no *C. virginica* larvae occurred near our study sites (Objective 4). Finally, we became actively

involved with local agencies and groups interested in *C. virginica* restoration efforts (NOAA, CBF, Friends of College Creek, UMD; Objective 5). In 2008 we will continue the work started in this project. Specifically, we will continue sorting the plankton samples to describe the planktonic assemblages in the region; deploy several drifters simultaneously to assess advection and diffusion in the study region, and compare our results to the predictions of a particle-tracking component of the ADCIRC model adapted for the Severn River.

Project Uses

The physical data collected as a part of this study will be made available to the public at http://usna.edu/Hydromechanics/ccbom/data.html. Knowledge of the physical conditions at the restored oyster bars may provide additional data to managers and policy-makers for decisions regarding the most economically and ecologically effective placement of oyster sanctuaries and restoration sites.

Cooperating Organizations

This work has facilitated collaborations with Ms. Stephanie Reynolds at the Chesapeake Bay Foundation, Rich Takacs and Peter Bergstrom at the NOAA Chesapeake Bay Office, Pierre Henkart of the Severn Riverkeeper's Association, and Elizabeth North at the University of Maryland. Specifically, we are actively sharing our oyster settlement and physical oceanographic data with CBF, NOAA, the Friends of College Creek, and the Severn Riverkeeper. This project has also provided baseline data for the 2008 MDSG Program Development Study "Advection and diffusion in estuaries and the coastal ocean; ground-truthing modeled particle trajectories with Lagrangian drifters."

Within USNA, the work conducted in 2007-8 has strengthened current collaborations with D.W. Fredriksson (Ocean Engineering) and A. Muller (Oceanography), and engendered projects with CAPT Jack Nicholson (Systems Engineering), and Mr. Bob Bruninga (Aerospace Engineering.)

Undergraduate Student Involvement

Many undergraduates were involved with data collection and analysis for this project. Part of this work served as the Honors Research projects for MIDN 1/C Jessica Orr (Fall 07) and MIDN 1/C Rob Pedersen (Fall 07-Spring 08). In addition, over 20 additional USNA Oceanography majors took turns collecting the CC temperature and salinity data in the fall of 2007.

Meeting/ Conference Presentations

Steppe, C.N., Fredriksson, D., Wallendorf, L., Barlow, A., Zepp, K. and Morgado, M. 2008. Connectivity among restored oyster bars in the Severn River Estuary; Implications for management. AGU Ocean Sciences Meeting, Orlando, FL, March 2008. (Accepted, but not presented due to medical emergency)

Steppe, C.N. 2007. Describing the physical and biological environment in College Creek; Contributions from USNA's Center for Chesapeake Bay Observation and Modeling. Chesapeake Bay Observing System Users' Forum. (* Poster presented by CDR E. Petruncio). Norfolk, VA. Dec 2007.

Steppe, C.N. 2007. Describing the Physical and Biological Environment in College Creek; Contributions of USNA's Center for Coastal Observation and Modeling. Friends of College Creek Workshop, Annapolis, MD. November, 2007.

Steppe, C.N. 2007. What drives population dynamics of marine fish and invertebrates? *Invited*. NSF-ADVANCE Women Evolving Biological Sciences Symposium, Seattle, WA. October, 2007.

Orr, J., **C.N. Steppe**, and R. Pedersen. 2008. "Potential Trajectories of *Crassostrea virginica* Larvae in the Severn River Estuary ," National Conference for Undergraduate Research. April, 2008, Salisbury, MD.

Pedersen, R., **C.N. Steppe**, and J. Orr. 2008. "Oyster Recovery Efforts in the Severn River Estuary; Assessment of *Crassostrea virginica* spatfall and growth at three restored bars," National Conference for Undergraduate Research. April, 2008, Salisbury, MD.

Pedersen, R., **C.N. Steppe**, and J. Orr. 2008. "Oyster Recovery Efforts in the Severn River Estuary; Assessment of *Crassostrea virginica* spatfall and growth at three restored bars," American Geophysical Union Ocean Sciences Meeting. March, 2008, Orlando, FL.

Orr, J., **C.N. Steppe**, D. Fredriksson, and A. Barlow. 2008. "Relating drifter buoy data and circulation patterns to the success of restored oyster bars," American Geophysical Union Ocean Sciences Meeting. March, 2008, Orlando, FL. (Accepted for presentation, but not presented by Steppe due to a medical emergency).

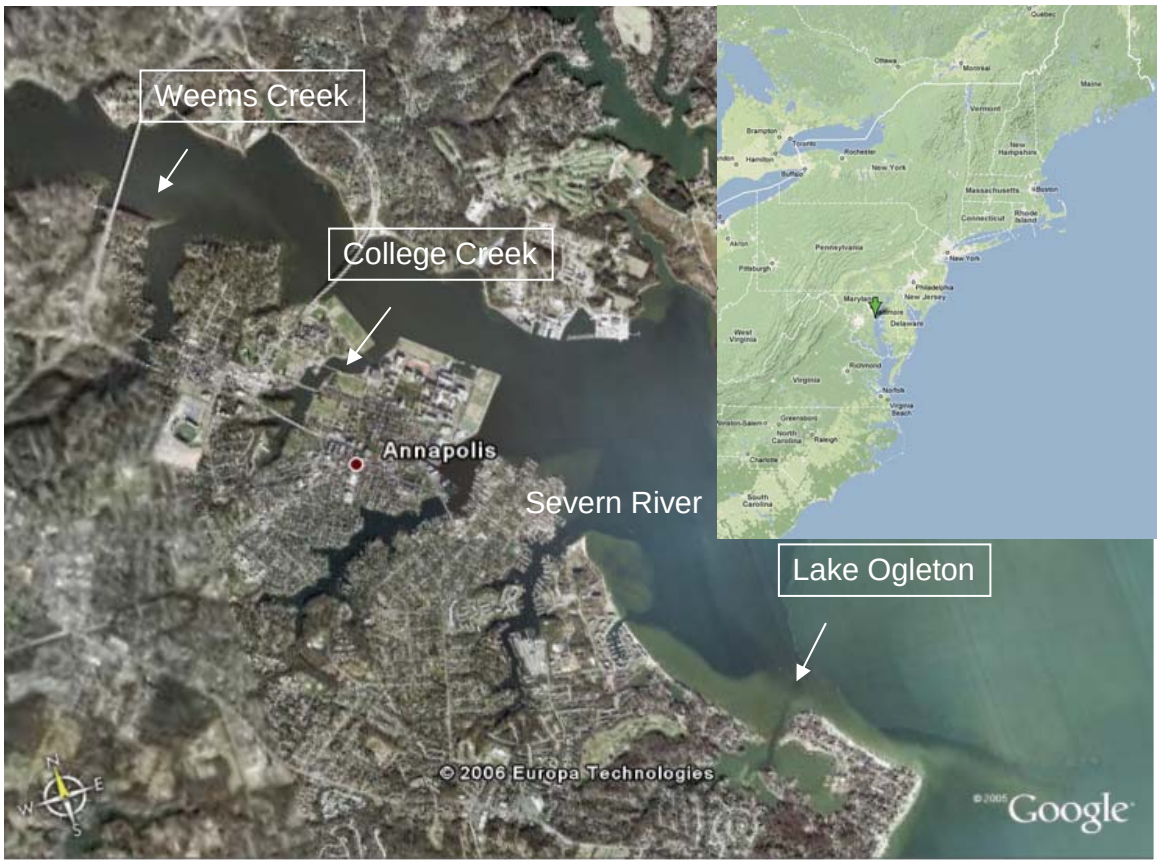

Figure 1. Locations of 3 restored *C. virginica* bars in the Severn River (Annapolis, MD USA). In the summer of 2007, temperature and salinity measured daily at College Creek, and weekly at Weems Creek and Lake Ogleton. Plankton tows were conducted weekly at each of the 3 sites, and all drifters were deployed at the mouth of College Creek. *By MIDN 1/C R. Pedersen

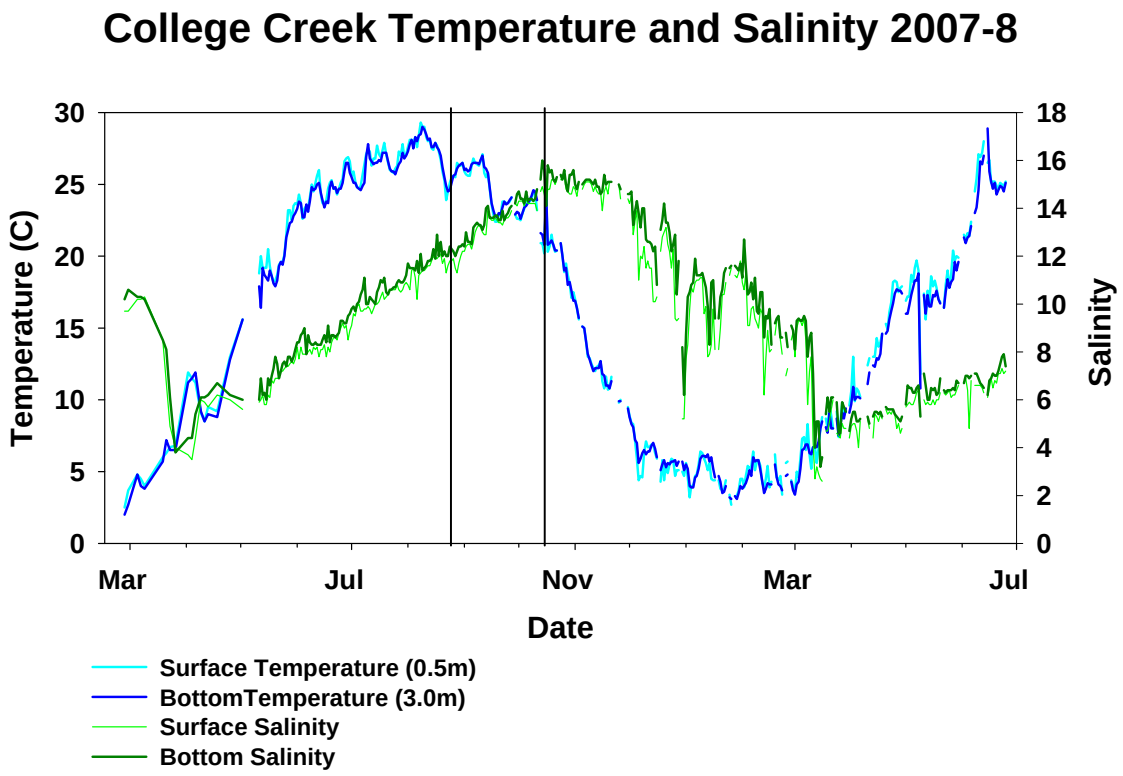

Figure 2. Daily measurements of temperature and salinity in College Creek. Black lines indicate a period in late August- November during which conditions were favorable for *C. virginica* spawning (temperature >20˚C, salinity >12).

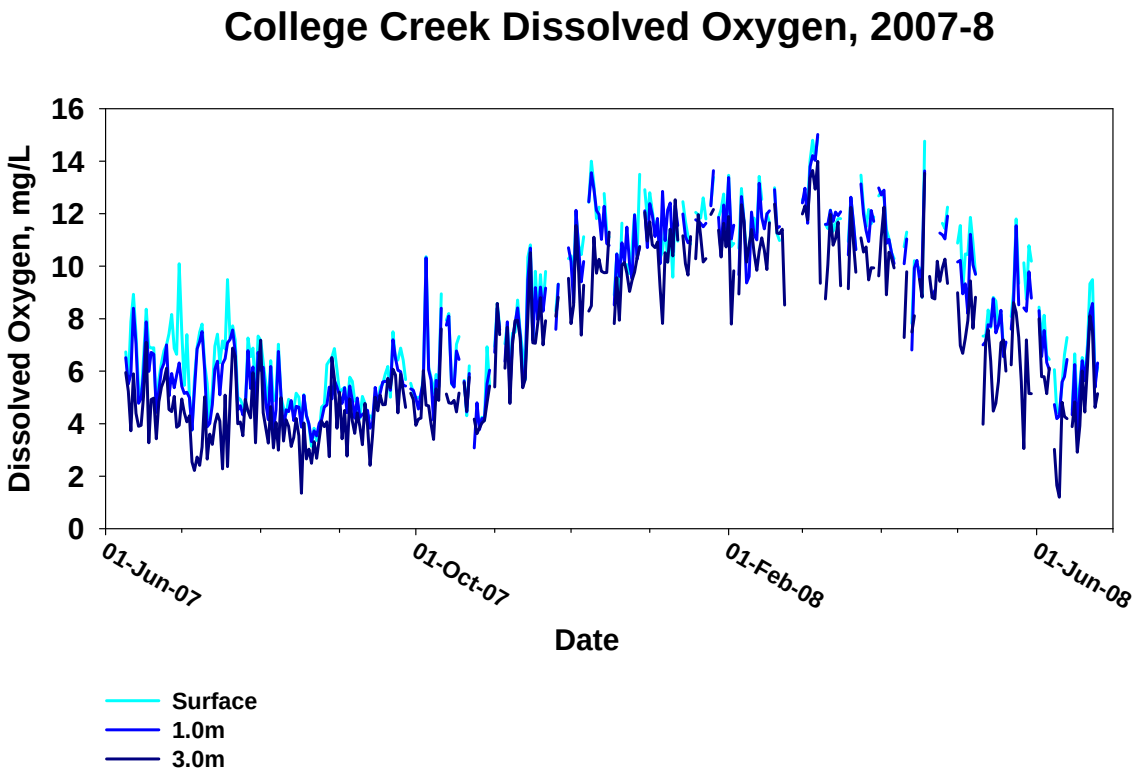

Figure 3. Daily dissolved oxygen readings in College Creek. Although during the summer, the mouth of the creek becomes hypoxic, most severely hypoxic episodes (<0.2 mg/L) at this site last less than 2 days.

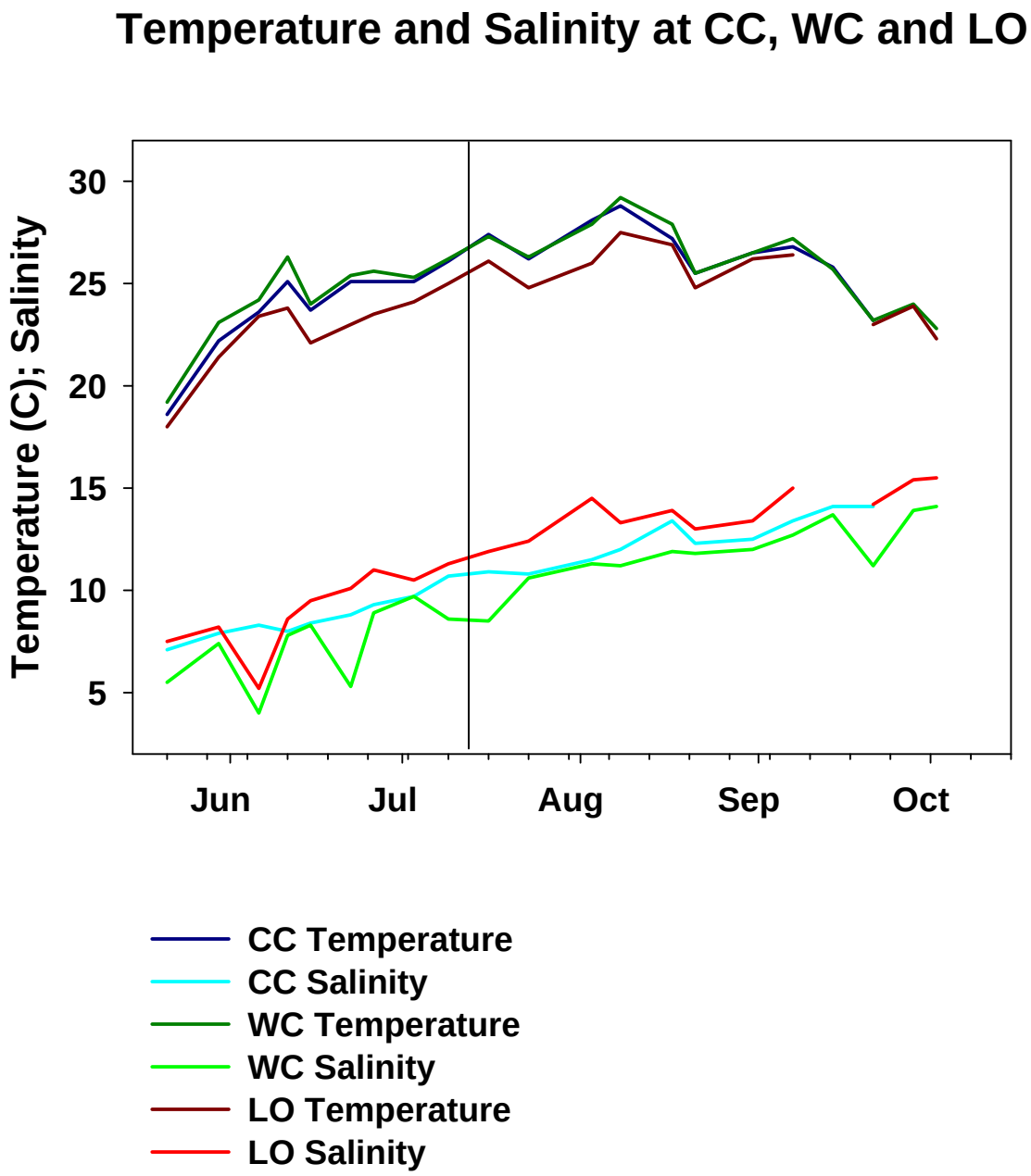

Figure 4. Bottom temperature and salinity at CC, WC and LO. Conditions favorable for *C. virginica* spawning (temperature>20˚C and salinity >12) occurred at LO by mid July. At CC and WC, salinity and temperature allowed possible spawning by mid-August.

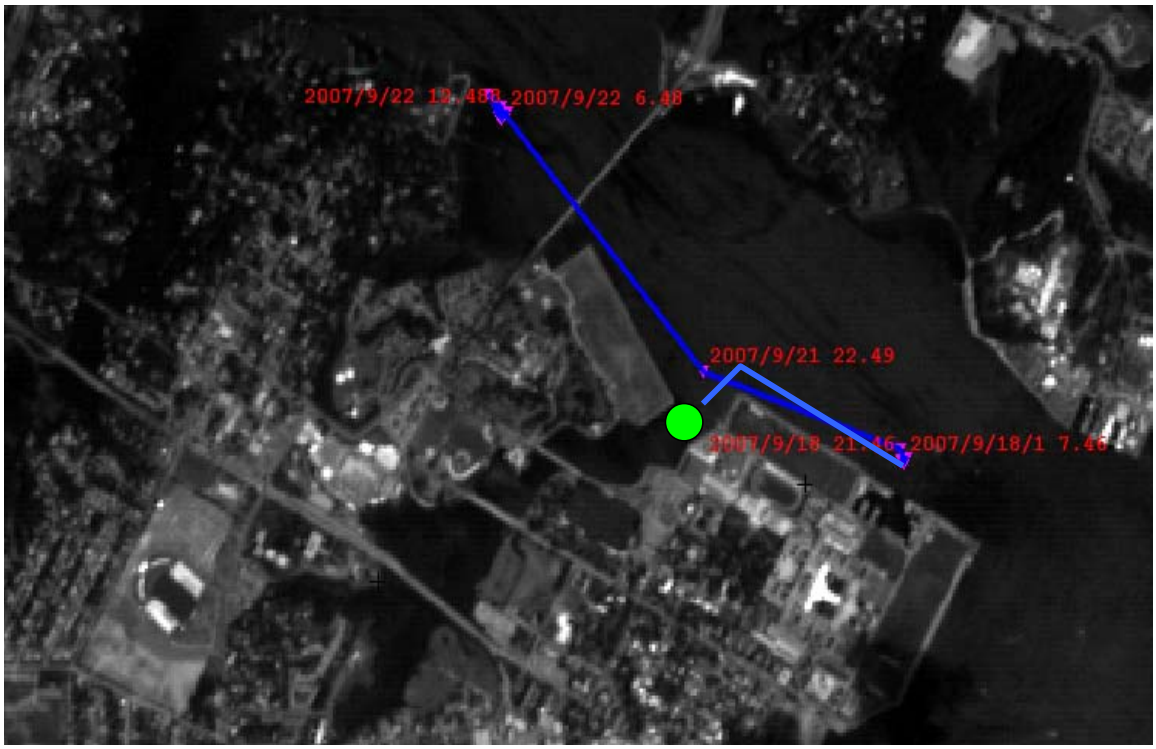

Figure 5. Drifter trajectory 18-22 September 2007. Green dot indicated location of deployment. The drifter was retained within the Severn River for 4 days prior to running aground. (Figure by MIDN 1/C J. Orr and C.N. Steppe)

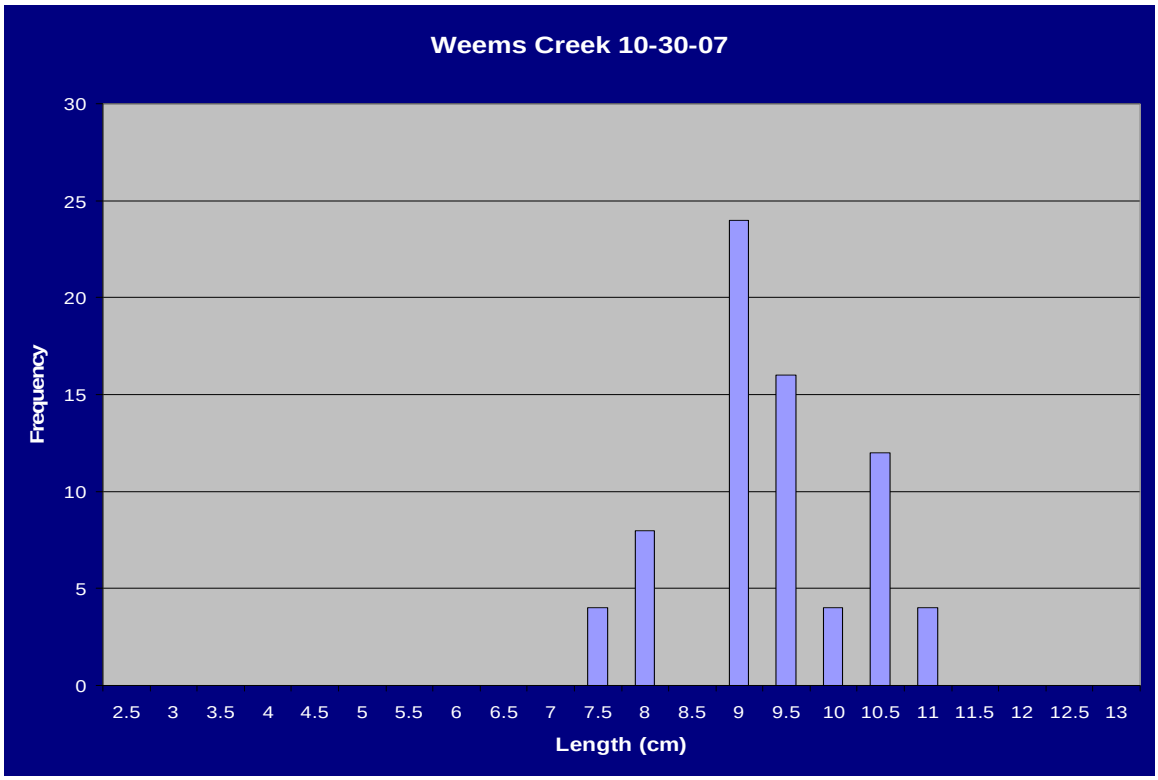

Figure 6. Histogram of *C. virginica* lengths in Weems Creek. The distribution indicates that likely a single cohort is present at this site. (Figure by MIDN 1/C R. Pedersen)

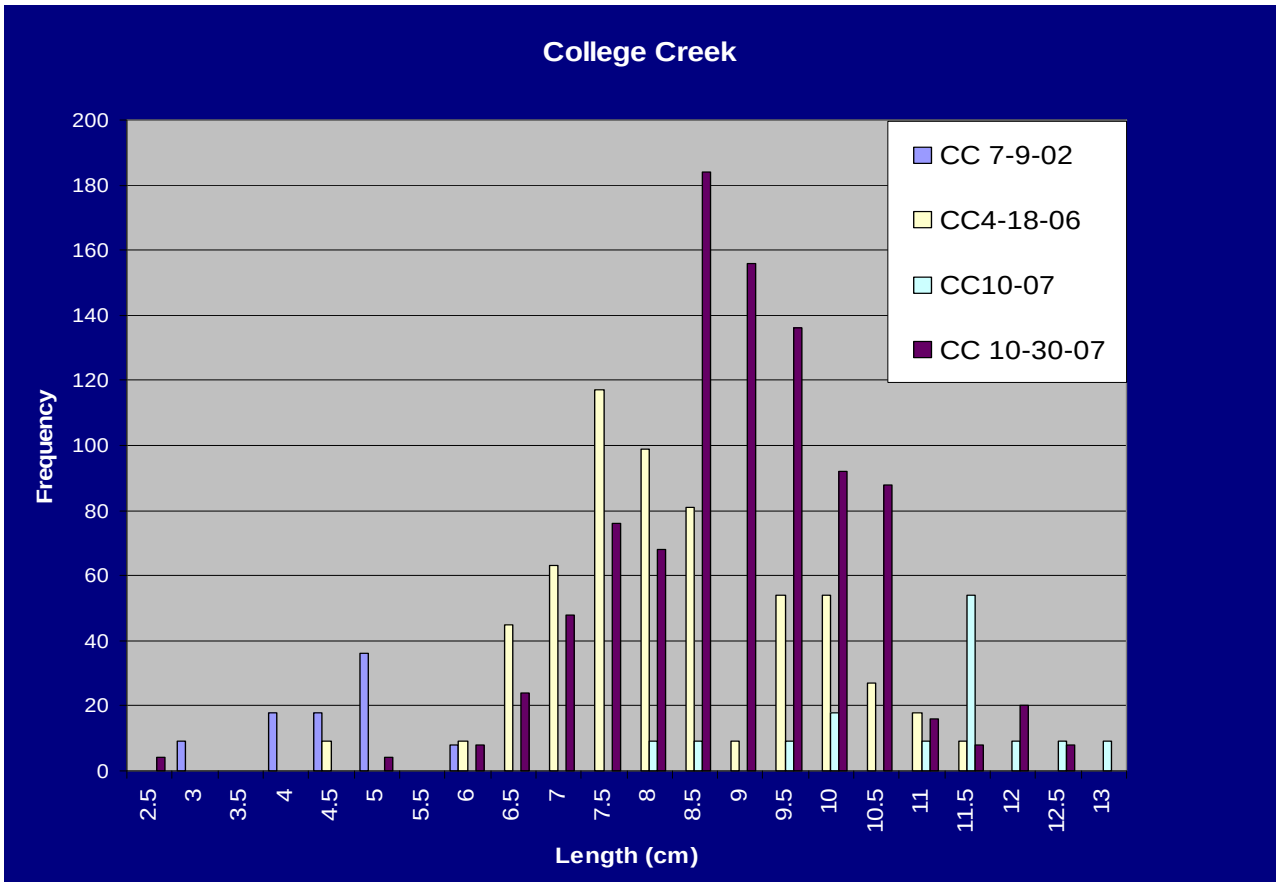

Figure 7. *C. virginica* growth at CC. Data indicate substantial growth of a cohort (planted in 2002) through time. The larger size classes represented by CC 10-07 may indicate that the part of the reef containing oysters grown in the oyster gardening program was sampled, and therefore may not represent the same cohort as those observed 10/30/07. Data from 2002, 2006 and early October 2007 were provided by Ms. Stephanie Reynolds (CBF) and Mr. Rich Takacs, NOAA Chesapeake Bay Office. (Figure by MIDN 1/C R. Pedersen).

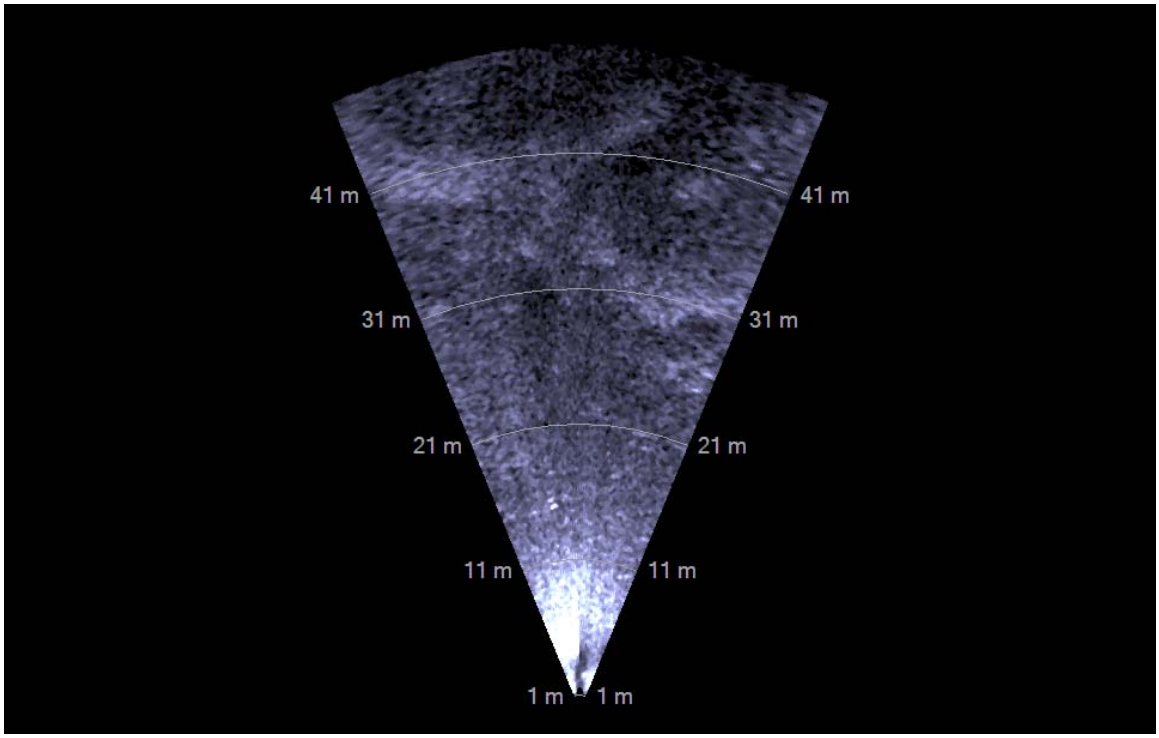

Figure 8. Example of imagery from BlueView acoustic camera. The edge of the WC reef can be seen as a diagonal impression from ~41m to 26m. While the acoustic data may be combined with GPS more mapping purposes, the data lack the resolution to be used to monitor oyster growth or mortality.